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Frequency-dependent Seismic Anisotropy in Fractured Rock

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Single fractures in rock can give rise to a variety of interesting seismic wave phenomena, including low-pass filtering of transmitted waves, the generation of reflected and converted waves, and the guiding of fracture interface wave (Schoenberg, 1980; Pyrak-Nolte *et al.*, 1990a; Pyrak-Nolte *et al.*, 1992). Although some work has been done on seismic wave propagation in rock with multiple fractures (e.g. Pyrak-Nolte *et al.*, 1990a; Schoenberg and Sayers, 1995), a comprehensive picture of the seismic wave phenomena produced by multiple fractures has yet to emerge. This paper uses numerical simulations to investigate the effects of multiple, parallel fractures on seismic waves propagating at normal, parallel and oblique incidence to the fractures and, in particular, examines channeling of waves between fractures and frequency-dependent seismic anisotropy.

To examine the effects of multiple, aligned fractures in rock, we have developed a two-dimensional elastic finite difference code for fractured media. Fractures are incorporated into the model explicitly as displacement-discontinuity boundary conditions. The wavefield is computed using a fourth-order staggered grid scheme. Simulations were performed for a broadband explosion point source (center frequency 374 Hz) located at the center of the model. The model consisted of 90 horizontal fractures spaced approximately 1/8 of a wavelength apart. The normal and shear fracture stiffness were selected such that the normal incidence transmission coefficient is 0.6. The simulation shows strong scattering attenuation of the P-wave in the vertical direction ($\perp$ to the fractures) and channeling of guided waves in the horizontal direction ($\parallel$ to the fractures). The same code was also used to model wave propagation in an anisotropic medium with equivalent effective moduli for the 90-fracture system. Significant differences between the amplitudes, velocities and frequency content of the waves in the explicit and equivalent medium fracture models were observed. These differences result from frequency-dependent time delays and filtering across each fracture, and channeling along fractures that are not included in the zero-frequency effective medium description. These effects are especially interesting because they illustrate that the dynamic properties of fractured rock include significant amplitude anisotropy that may prove useful in the characterization of fractured rock.

Keywords: fracture anisotropy; fracture interface waves; transversely isotropic model; explicit fracture model; displacement-discontinuity boundary condition

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